Prediction of the Epidemic Nodal State from Reported data

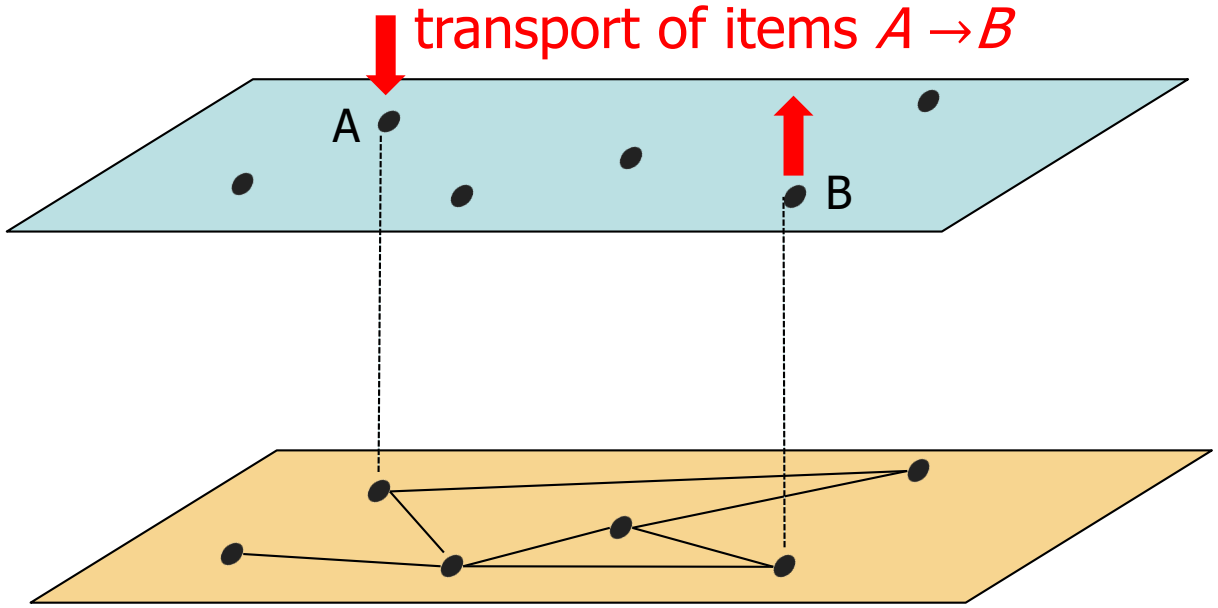
Piet Van Mieghem

in collaboration with
Bastian Prasse, Massimo Achterberg, Long Ma, Stojan Trajanovski and Maksim Kitsak

Virtual 40th International Symposium on Forecasting, ISF 2020
Rio de Janeiro, 26-28 October, 2020

TU Delft

Network = Process + Graph



Process (Function)

Software, service

Graph (Structure)

Hardware, Topologie
Relationship between items and/or processes

Network Science: Theory of processes on/in graphs

Duality between process and graph is a cornerstone

TU Delft

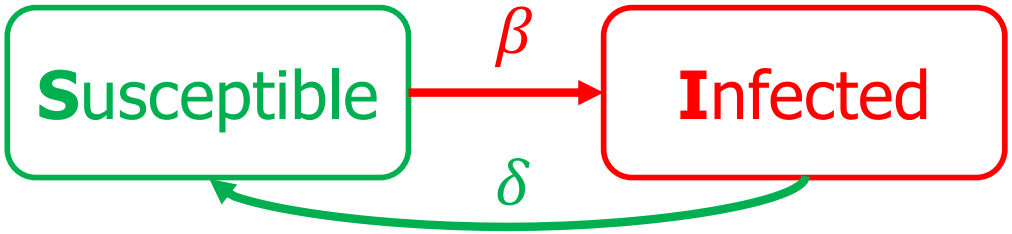
Epidemics on Networks in brief

- Closed population with N individuals:
  - Accurate models for any compartment on any *fixed* graph (mean-field approximation & Markovian setting)
  - *Open*:
    - non-Markovian
    - time-varying networks
    - adaptive networks
- Open population:
  - In contrast to classical epidemics, hardly any network science paper
    - Complication: graph with variable number of nodes

Epidemic "compartiments"

Single disease realization

Diseases with re-infections



Essence: item can only be in 1 compartment at time t

Sahneh, F. D., C. Scoglio and P. Van Mieghem, "Generalized Epidemic Mean-Field Model for Spreading Processes over Multi-Layer Complex Networks", IEEE/ACM Transactions on Networking, Vol. 21, No. 5, pp. 1609-1620, 2013.

TU Delft

SIS Mean-field Equations in discrete time k

Difference equation of infection probability $I_i[k]$ of node i:

$$I_i[k+1] = \boxed{(1-\delta_i)I_i[k]} + \boxed{(1-I_i[k])\sum_{j=1}^{N}\beta_{ij}I_j[k]}$$

curing

infections

δ_i: Curing probability of group i ($N \times 1$ vector δ)

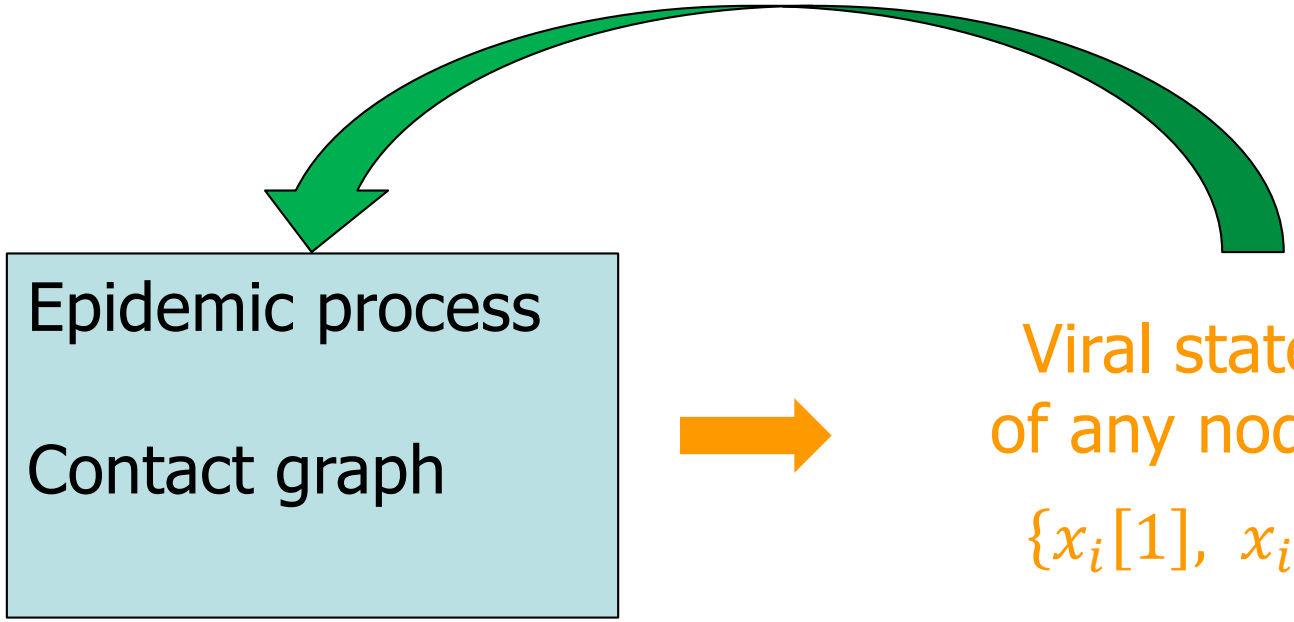
β_{ij}: Infection probability from group j to group i ($N \times N$ matrix B)

Non-linear in vector I[k], but **linear** in vector δ and matrix B

Prasse, B. and P. Van Mieghem, 2019, "The Viral State Dynamics of the Discrete-Time NIMFA Epidemic Model", IEEE Transactions on Network Science and Engineering, to appear.

Prasse, B. and P. Van Mieghem, 2020, "Network Reconstruction and Prediction of Epidemic Outbreaks for General Group-Based Compartmental Epidemic Models", IEEE Transactions on Network Science and Engineering, to appear.

Inversion



Network Inference-based Prediction Algorithm (**NIPA**)

Viral state sequence of any node i in graph

$\{x_i[1],\ x_i[2], \ldots, x_i[n]\}$

Linear, but **seriously underdetermined** problem

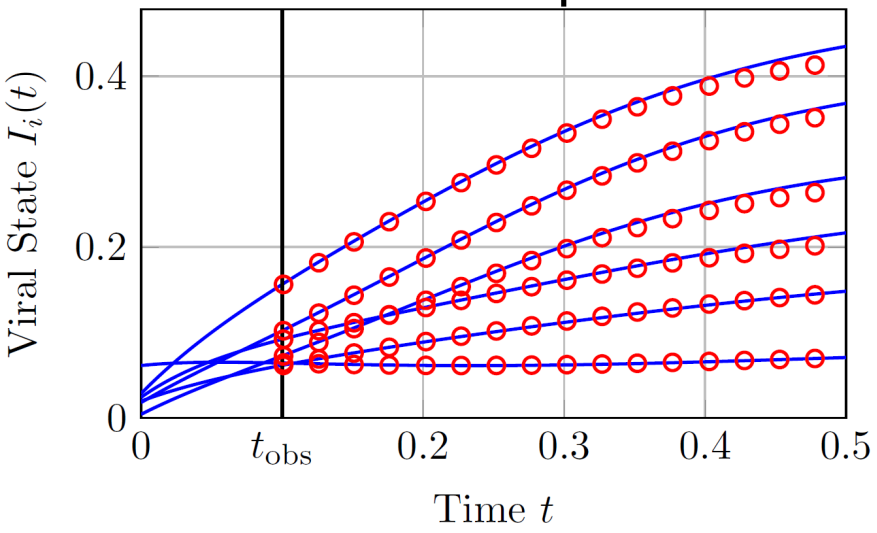
Optimization with constraints (Lagrange's multipliers):

- very effective numerical techniques
- beyond Gauss's least square criterion (e.g. LASSO)

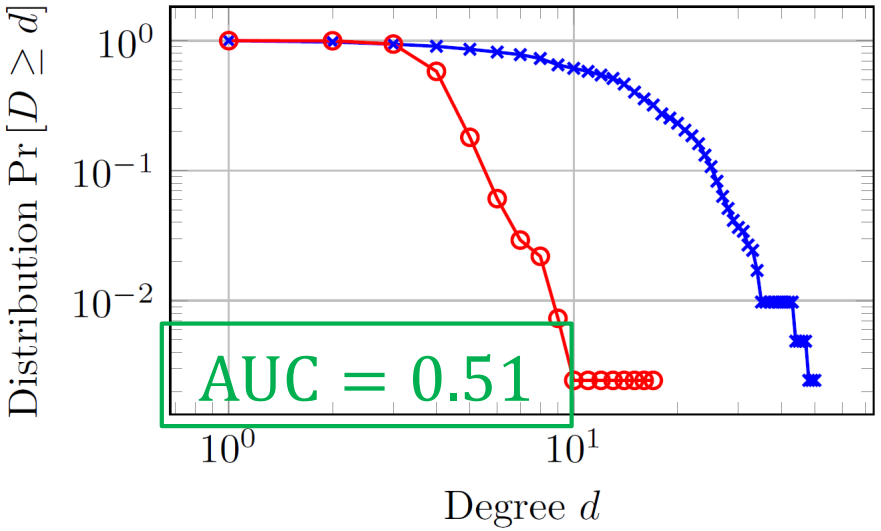
R. Tibshirani, "Regression shrinkage and selection via the Lasso," Journal of the Royal Statistical Society: Series B (Methodological), 1996

Excellent prediction *process;* bad *graph*

Prediction of process



Reconstruction of graph



Accurate prediction of network dynamics ***without*** knowing the network's topology

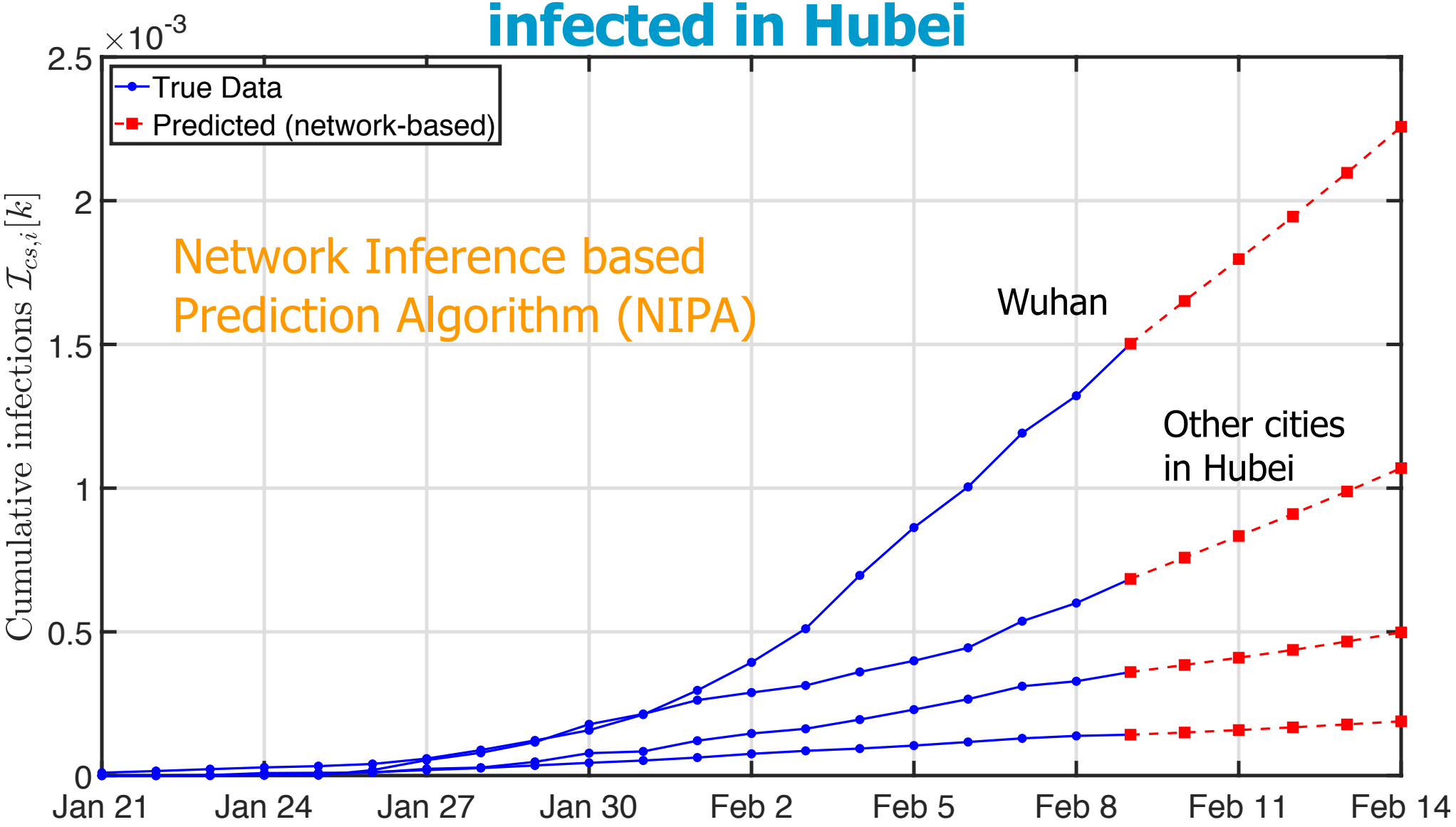
Reason: one virus outbreak agitates few network dynamical modes. Not only for epidemics but also e.g. :

Population dynamics (Lotka-Volterra), Gene regulatory dynamics (Michaelis-Menten), Neural firing (Wilson-Cowan)

B. Prasse and P. Van Mieghem, 2020, "Network Reconstruction and Prediction of Epidemic Outbreaks for General Group-Based Compartmental Epidemic Models", IEEE Transactions on Network Science and Engineering, to appear

TU Delft

Expected Cumulative Fraction of COVID-19 infected in Hubei



B. Prasse, M. A. Achterberg, L. Ma and P. Van Mieghem, "Network-Based Prediction of the 2019-nCoV Epidemic Outbreak in the Chinese Province Hubei", arXiv: 2002.04482 (**12 Febr. 2020**)

TU Delft

Conclusion

- Given infected data in space (network) & time:
  - Accurate short-time predictions **possible with NIPA**
  - Accurate long-time predictions **hardly possible**

Discussion panel (observations):

- Insufficient measurements ("meten = weten")
- Digital technology (e.g. apps on smart phone, base-stations, sensors, etc.)
  - Insufficiently exploited (privacy)
  - Less costly than vaccine development
- No optimized "COVID-19" strategy
  - Each country claims the best method
- Political choices in triangle *freedom-health-economy*


Thank You
Piet Van Mieghem
NAS, TUDelft
P.F.A.VanMieghem@tudelft.nl

TU Delft